Optical control of mesoscopic spin ensembles in gallium arsenide

Onur, Alexander

Chapter 9

Conclusion and outlook

The phenomenon of electromagnetically induced transparency (EIT) with donor-bound electrons in GaAs (D^0 systems) is an important precursor to allow for light storage and all-optical switching in this material. The fact that this is achievable in a common semiconductor material as GaAs is relevant for future applications, because the large body of expertise on growth and processing techniques for this material can facilitate the step to device fabrication. The measured electron spin dephasing time of 3 ns (Chapter 2) is however rather short for progressing to experiments on stored light. The effective lifetime of the associated spin coherence so short that verifying properties like spin-spin or spin-photon entanglement is very challenging, even in a laboratory setting.

The fact that the EIT resonance can serve as a probe for the nuclear spin polarization makes it also a useful tool for investigating changes induced in the nuclear spin bath by dynamic nuclear spin polarization (DNP). Using a differential transmission spectroscopy technique we have shown the possibility to measure the build up and decay times of DNP near donor bound electrons in GaAs. We find the DNP dynamics to take place on a timescale of minutes (Chapter 3) under the experimental condition of a strong magnetic field of 6.4 T and low temperature of 4.2 K. This implies the possibility to first prepare the nuclear spins and then to perform the manipulations on the electron spin (in the modified nuclear spin bath).

The method developed to reduce fluctuations of the nuclear spins along the external magnetic field can improve the electron spin coherence time. This all-optical method has as advantage that it can reduce the nuclear spin fluctuations while giving direct optical feedback by enhanced laser transmission through the sample. In Chapter 4 we use the model with parameters representative for case of the D^0-D^0X in GaAs, to yield an improvement factor of 7. The implementation of the proposal, Chapter 5, shows half of the effect: A splitting is visible for the predicted configuration, but the narrowing is not. The fact that this splitting is indeed observed nevertheless confirms that the two-laser DNP driving scheme is compatible with both predicted effects. For further experiments to confirm this it is important to improve the intensity distribution of the pumping lasers inside the sample. Based on the current results we expect that because the DNP is an intensity dependent effect, the variation of intensity within the laser spot (due to the Gaussian beam profile and Fabry-Perot interference inside the sample) can obscure the nuclear spin narrowing effect. Anti-reflection coating on the sample and aperture to create a homogeneous laser spot could resolve this.

Chapters 6 and 7 provide supporting information for the DNP experiments in earlier chapters. The measurements in Chapter 6 were originally intended to reinforce the proof that DNP was observed by checking the dependence on pump laser frequency. If shifts in EIT resonance should occur for pumping off resonance with the exciton states (into the conduction band, or deeper inside the bandgap) this would shed a different light on the statements in Chapter 3. The results were in accordance with our expectations, but a surprising effect was that pumping inside the exciton line turned out an easy method to create large Overhauser fields (300 mT) of either sign, depending on the pump laser frequency. Because local magnetic fields are not an easy resource to come by in spintronics (magnetic fields are often generated over large volumes using electromagnets), such internal magnetic fields could prove useful.

Besides improvements on the GaAs measurements, there is the possibility to apply the techniques used in this thesis on other systems. The nuclear spin narrowing proposal of Chapter 4 has some generality and it could be explored in quantum dots or localized spins in other semiconductors (as we also discuss in the chapter). The recently measured CPT on localized spins in silicon carbide is another example (described in reference 6 on page 151). This is a deep defect, as opposed to the shallow donor in GaAs. The possibility to eliminate the nuclear spins from this material is promising. A downside is that electrons of the deep defect, which are highly localized on the defect lattice sites, couple to vibronic modes of the defect. This results in a large portion of emission in the phonon-side band while emission into the zero phonon line is wanted for quantum information related work.